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ABSTRACT

Using near-simultaneous full disk Solar x-ray images and He I 10830λ spectroheliograms from three recent rocket flights, we compare dark points identified on the He I maps with x-ray bright points identified on the x-ray images. We find that for the largest and most obvious features there is a strong correlation: most He I dark points correspond to x-ray bright points. However, about two-thirds of the x-ray bright points were not identified on the basis of the helium data alone. Once an x-ray feature is identified it is almost always possible to find an underlying dark patch of enhanced He I absorption which, however, would not *a priori* have been selected as a dark point. Therefore, the He I dark points, using current selection criteria, cannot be used as a one-to-one proxy for the x-ray data. He I dark points do, however, identify the locations of the stronger x-ray bright points.

1. Introduction

The name "x-ray bright point" or XBP was given to the numerous small regions of enhanced emission which were seen on early high resolution x-ray images (Vaiana *et al.* 1970) of the Solar corona. For large, long-lived regions, whenever detailed comparison between coronal features and magnetic field maps is performed, one finds that non-flaring coronal emission is associated with closed loop structures which appear as bipoles on magnetograms and as loops in x-rays (Vaiana and Rosner 1978). For the smallest features the comparison is not as striaghtforward, particularly because there are many small magnetic bipoles which are not associated with any obvious x-ray emission. The XBP, which are associated with magnetic bipoles, are so numerous that if they are caused by newly emerging magnetic flux, then they could be responsible for the vast majority of the emerging magnetic flux coming to the Solar surface (Golub *et al.* 1977).

The sharp division in x-ray brightness between open and closed regions is particularly useful for identifying and studying small bipolar regions. Such studies have indicated that the vast majority of closed, compact emission features in the corona correspond to regions having lifetime τ of two days or less (Golub *et al.* 1974). For the larger ($\tau > 2$ days) regions, it is clear that they represent emerging flux: these regions generally develop arch filament systems and pores, and occasionally small sunspots. The more numerous shorter-lived regions exhibit fewer indicators of flux emergence; until now we have only established that there is a statistical correlation between magnetic bipole separation and magnetic flux, and the age of the XBP (Golub *et al.* 1977).

Unfortunately, because x-ray observations can only be obtained from instruments above the atmosphere, only infrequent sounding rocket x-ray data with sufficient spatial resolution and sensitivity to detect XBP have been obtained since the Skylab mission. On the other hand, daily groundbased full disk He I $\lambda10830$ spectroheliograms have been available since *Skylab* from the National Solar Observatory (NSO) at Kitt Peak. The Helium data have been used, among other things, for studying the small regions which are called "dark points" when seen in Helium, under the working hypothesis that there is a one-to-one association between dark points and XBP. This assumption is based on a study carried out in 1973 (Harvey *et al.* 1975) using some of the earliest He I data available. This study was

a qualitative comparison of four pairs of observations in x-rays and He I D_3, which is essentially identical to He I 0830 (Harvey and Hall 1971; Giovanelli *et al.* 1972).

The He $\lambda10830$ absorption line is produced by He I in its triplet state. It is formed in the chromosphere, at about the same height as the Ca K and H_α lines. Goldberg (1939; see also Zirin 1975; Kahler, Davis and Harvey 1983) suggested that UV emission from the corona can overpopulate the triplet state of He I through photoionization followed by recombination. This model explains the resemblance between He I spectroheliograms and x-ray maps, as well as the presence of a faint network similar to that which can be seen in Ca K or H_α.

Because of the correlation between x-ray emission and He I absorption, combined with the relative lack of x-ray data in recent years, there has been a tendency within the Solar community to use the He I $\lambda10830$ spectroheliograms as a substitute for the unavailable coronal x-ray data. While this has been shown to be justified in the case of large, long-lived structures such as active regions and coronal holes (Kahler, Davis and Harvey 1983), quantitative comparisons of the smallest features have not until now been carried out. The purpose of this letter is to show that the validity of using He I dark points as a proxy for x-ray bright points is limited and that He I $\lambda10830$ maps and x-ray images, despite evident similarities, cannot be used interchangably.

2. Comparison of He I λ10830 and X-ray Data

K. Harvey (1985) conducted an extensive survey of NSO magnetograms and He I λ10830 spectroheliograms collected from 1970 to 1984, partly as an attempt to analyze in detail the connection between magnetic activity and small coronal features. Within the time frame of this study, three x-ray datasets which are appropriate for use in this study were obtained from flights of the A.S.&.E. rocket-borne grazing incidence telescope (see Vaiana *et al.* 1973 for instrument description). Near simultaneous (i.e., within two hours) ground-based data were obtained for these flights, as summarized in Table 1. Note that full disk Helium and magnetic field scans take approximately 40 minutes each; times listed in the table are start times.

Table 1. Dates and Times of X-ray, He I and Magnetogram Data Used.

Date	X-ray (UT)	He I 10830	Magnetogram
6/27/74	1948	1605 1657 1804	1508 1854
9/16/76	1803	1841	1532
11/16/79	1703	1646	1543, 1743, 1828, 1917, 2007, 2100

We have performed the comparison as a double-blind experiment. Using these datasets we compared the XBP as marked by one of us (L.G.) against the He I dark points identified separately (by K. L. H.). The procedures for selecting x-ray bright points have been discussed in our earlier papers, but may be summarized briefly as follows: we examine the photographs for small, compact, isolated regions of x-ray emission. This may be pointlike, or give the appearance of elongated loop structure, or they may be fairly diffuse and best described as "cloudlike". The main criterion is that the region be self-contained and clearly isolated from any larger structure. The upper limit on size is arbitrarily taken

to be one arcminute.

Dark points were selected on the basis of a visual inspection of the He I λ10830 spectroheliograms using as criteria the size and intensity of isolated structures. Structures identified as dark points are typically less than 40 arcsec in extent, although some larger regions are included, particularly those in coronal holes, having an intensity at least 20% darker than the surrounding network. No attempt was made to eliminate filament fragments which can have a similar appearance. Consistency in the selection of features that are dark points depends strongly on the day-to-day variations of the calibration of the He I λ10830 data and the print quality.

The result of this comparison is best illustrated visually as in Figure 1. This figure shows the central portions of the He I and x-ray images obtained on 27 June 1974, and it illustrates the result which we find in general for all of the observations. There are four categories of correspondence between the two images. These are: He I dark points which *are* and *are not* associated with XBP, and XBP which *are* and *are not* associated with dark points.

In Figure 1 only three of these categories needed to be labelled since the last category was not present. That is, there were no XBP which did not have an associated He I feature. Thus, the figure contains three types of overlay symbols: a solid circle indicates an XBP located at the place where a He dark point was identified, a dotted circle indicates an XBP which did not have a *previously* identified He dark point, and a square indicates a helium feature which did not have an XBP.

The major conclusions reached from comparison of the x-ray and He I λ10830 data are:

1. There are, in general more XBP identified than there are He I dark points selected - 162 compared with 65;

2. Most of the dark points have corresponding XBP - 53 out of 64. In the few cases for which there is no XBP present, the helium feature tends to be a piece of filament material. Filaments appear as absorption features in He I λ10830, much as they do in Hα.

3. In essentially every case, an XBP can later be associated with a patch of He I absorption.

Results 1 and 2 are summarized quantitatively in Table 2.

Table 2. Statistics of Dark Point/Bright Point Identifications.

Date	# d.p.	# XBP	# d.p. w/o XBP	# XBP w/o d.p.
6/27/74	31	58	1	27
9/16/76	26	90	6	70
11/16/79	9	14	5	10

Explanation of column headings:

d.p. = number of He I dark points identified
XBP = number of x-ray bright points identified
d.p. w/o XBP = number of He I dark points which did not have corresponding x-ray bright points
XBP w/o d.p. = number of x-ray bright points which did not have *previously selected* dark points.

The key numbers in this table is listed in the last two columns. Our comparison shows that only ¼ to ½ of the x-ray bright points correspond to helium features which are identified on the basis of the He I data alone. It is, of course, quite possible that essentially all of the XBP correspond to helium features, which would be consistent with the small number of dark points without XBP, shown in the table's fourth column. However, the results of this study show that using present identification methods, ½ to ¾ of the x-ray bright points may not be located on the basis of the He I λ10830 data. On the other hand most He I dark points correspond to x-ray bright points, specifically the brighter ones (see Figure 1).

Although there are major differences apparent when comparing the two sets of small scale features, the statistical results should be viewed with caution because of two important considerations. As can be seen from Table 1, the datasets are not strictly simultaneous and it can be argued that the short lifetime and rapid variability of helium dark points and x-ray bright points may be partially responsible for the lack of correlation between the two maps. This may be particularly true for the

smaller, weaker x-ray bright points which, if they are not in the very early or very late stages of development, characteristically have shorter lifetime than the larger XBP (Golub *et al.* 1974).

The second point is that the selection criteria for x-ray bright points and helium dark points are somewhat subjective. Our analysis of the correlation between x-ray bright points and helium dark points is based on today's best effort. We do not rule out the possibility of empirically developing a reliable automated selection algorithm, perhaps in conjunction with magnetic field and H_α information.

3. Implications

On the basis of the assumed correlation between XBP and emerging magnetic flux certain major conclusions were reached: that the small regions contribute the majority of the emerging flux at nearly all phases of the Solar cycle (Davis, Golub and Krieger 1977), and that this would lead to an anticorrelation in the cycle behavior between the large (active regions as represented by sunspots) and the small (XBP) emerging regions (Golub, Davis and Krieger 1979; Davis 1983). By arguing that bright points are associated with small regions of emerging magnetic flux, Golub *et al.* 1979 put forward the suggestion that the Solar cycle is a variation in the size distribution of new emerging flux rather than a variation in the total quantity of flux.

Recent studies have greatly confused this proposed picture. In particular, time sequences of high resolution magnetograms show that many, if not most, of the observed small bipoles represent "chance encounters" of small opposite polarity magnetic elements which appear to come together and disappear (Martin *et al.* 1985). The work done by Harvey (1985) shows that two-thirds of the He I dark points are associated with chance encounters of opposite polarities, while the remaining one-third result from emerging new flux. If one were to assume that the He I dark points identify all of the XBP, instead of the fraction which we report here in Table 2, then we would conclude that chance encounters are mainly responsible for the XBP. The conclusions reached by Golub, Davis and Krieger (1979) would therefore be incorrect (Zwaan 1987).

Even though we have shown in this paper that there is a limit in finding from the ground-based data alone all of the XBP, this limit is largely irrelevant to the earlier bright point studies. The reason is that most of the earlier bright point studies were done using short x-ray exposures (Golub *et al.* 1977) in order to eliminate possible bias caused by the varying large scale coronal structures and coronal holes. Thus, the bright points studied were the largest and most easily seen, and those correspond quite well to the features selected in the Helium λ10830 data. The data used in the present study were taken with a different telescope than the one used on Skylab, but we attempted to chose exposure times which would produce images as close as possible to those used in the earlier work.

In Golub, Harvey and Webb (1986) we examined the relationship between XBP and ephemeral magnetic regions, using these same x-ray data and near-simultaneous magnetograms. Our conclusion was that the separation of the ER into encounters between opposite polarity network elements and emerging bipoles makes almost no difference in the probability of seeing an x-ray feature. Thus, if two-thirds of the magnetic features are chance encounter ("reconnection") events, then two-thirds of the x-ray features will by probabilities alone also be associated with reconnection events. The XBP which we studied would then be dominated by chance encounters and should have the same Solar cycle properties as the He I dark points.

The question remaining is why the XBP show an anticorrelation with the Solar cycle, as do the dark points (Harvey 1985), while the ER do not behave the same way. Unfortunately, we are not at this time in a position to answer this crucial question. A possible answer may be provided by noticing that the fractional area coverage of mixed polarity on the Sun is anticorrelated with the Solar cycle (Giovanelli 1979). The fraction of the Sun's surface covered by mixed polarity field tracks well with the variation in XBP number as a function of phase in the Solar cycle. However, Golub *et al.* (1977) established quite clearly that the size and lifetime of an XBP correlates well with the quantity of magnetic flux in the bipolar region. It is not clear whether area coverage of mixed polarities in itself is sufficient to explain the XBP variation, as Harvey (1985) argued, since field strength or quantity of flux in the region should also be a factor. For example, if at Solar minimum the mixed polarity field on the Sun consists of relatively small bits of magnetic flux, then the distribution of XBP lifetimes should be skewed toward short-lived regions. However, since the *Skylab* mission we have not had any time resolved x-ray data from which to determine changes in the XBP lifetime distribution as a function of Solar cycle. Moreover, it will be possible to make such a differentiation only if the distribution of lifetimes or fluxes for the emerging regions is different than that of the chance encounters.

The detailed comparisons between x-ray and magnetic data, with time resolved sequences of both, were done during the *Skylab* mission. At that time the magnetograph being used had lower spatial resolution and sensitivity than the present instrument. In the intervening fifteen years, no time sequences of high resolution x-ray data have been available. A step toward an answer may be pro-

vided by future flights of x-ray telescopes with higher spatial resolution, which could provide snapshots of the detailed structure within XBP, as well as time sequence observations to study the relation between XBP and the evolving underlying magneti field. Such data may show a difference in topology between emerging and reconnecting features, which would at least help in determining whether there are differences in the coronal behavior of these two different kinds of magnetic regions. If we can successfully differentiate between the two types of region then one would expect that the two classes would have different Solar cycle properties, as determined by time-resolved data.

4. Acknowledgements

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5. References

Davis, J.M., L. Golub and A.S. Krieger 1977, *Ap. J.*, **214**, L141.

Davis, J. M. 1983, *Sol. Phys.*, **88**, 337.

Giovanelli, R. G., D. Hall and J. W. Harvey 1972, Solar Physics, **22**, 53.

Golub, L. 1980, *Phil. Trans. R. Soc. London A*, **297**, 595.

Golub, L., A.S. Krieger, J.W. Harvey and G.S. Vaiana 1977, *Sol. Phys.*, **53**, 111.

Golub, L., K. L. Harvey and D. F. Webb 1986, NASA CP-2442, ed. A. I. Poland, p.365.

Harvey, J. W. and D. Hall 1971, IAU Symp. **43**, 279.

Harvey, J. W., A. S. Krieger, A. F. Timothy and G. S. Vaiana 1975, in G. Righini (ed.), "Skylab Solar Workshop", Oss. e Mem. Osservatorio di Arcetri, **104**, 50.

Harvey, K. 1985, Australian J. Phys., **58**, 385.

Kahler, S. W., J. M. Davis and J. W. Harvey 1983, *Sol. Phys.*, **87**, 47.

Vaiana, G.S., A.S.Krieger and A.F. Timothy 1973, *Sol. Phys.*, **32**, 81.

Zwaan, C. 1987, *Ann. Rev. Astron. and Astroph.*, **25**, 83.

6. Figure Caption

Figure. 1. a) He I λ10830 spectroheliogram taken at 1657 UT (end at ~1740 UT) on 27 June 1974. Overlay indicates comparison with x-ray bright points, as follows: solid circle indicates He I dark point with corresponding XBP, dotted circle indicates location of XBP for which no He I feature was selected and squares indicate small pieces of filament material.

b) X-ray image obtained at 1948 UT on 27 June 1974.

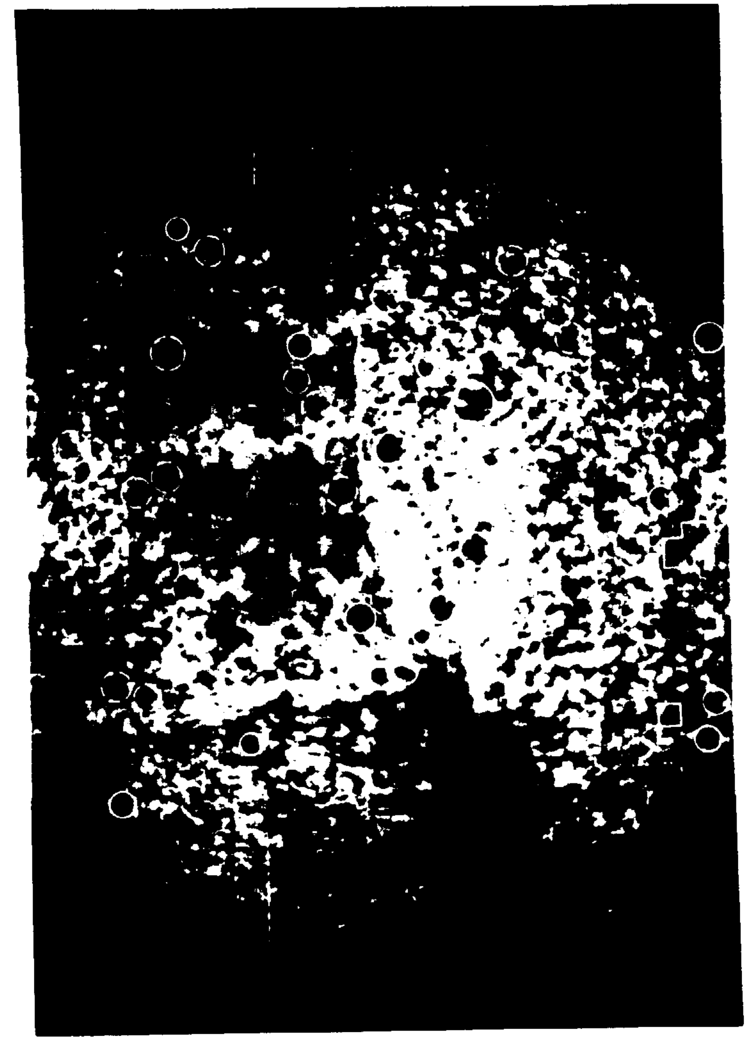

Fig. 1a

Fig. 1b

4.22 Advanced in Photographic X-Ray Imaging for Solar Astronomy

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